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An Energy Based Approach of Electromagnetism Applied to Adaptive Meshing and Error Criteria

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Abstract—In order to improve the reliability of the electromagnetism modeling tools, we propose an original way to evaluate the mesh numerical error for magneto-dynamic cases. An original error criterion for conducting pieces, based on a local conservation of the power, is detailed. Some remeshing results are displayed for a simple 2D magneto-harmonic case.

I. INTRODUCTION

The modeling of eddy-currents represents a considerable stake for optimizing both performances and energy efficiency of electro-mechanical devices. In an eco-designing outlook, it is necessary to consolidate all the energies spent during the lifetime of a product, to achieve its Life Cycle Assessment. The precision in the calculations of energy quantities is then a crucial point and has to be ensured at each step of design and modeling.

In this paper, we are concerned with the macroscopic eddy-currents, due to a time varying excitation and/or the movement of a massive conductor. In the Finite Element Method, the correct modeling of those phenomena is widely linked to the mesh, especially in massive conductors, where it has to take account of the skin effect. This problem becomes crucial for 3D cases. If the mesh is too refined, the case uses too much memory space, and if the mesh is not accurate enough, the computation cannot run. That is the reason why we focused on adaptive meshing.

We propose an original way to improve the mesh in order to have it adapted to the physical phenomena. The technique is based on a thermodynamic approach of electromagnetism that leads to a new error criterion for conducting regions. Some considerations about order element are discussed, and finally an example of a remeshing technique is shown on a 2D induction heating case.

II. AN ORIGINAL ERROR CRITERION FOR MASSIVE CONDUCTORS

A. From thermodynamics to a priori error evaluation

It is possible to derive electromagnetic laws from thermodynamics considerations [1]. This approach is consistent with Finite Elements, and addresses a deeper justification of this method to model the electromechanical

conversion. It consists in building an approximation of the power functional (1) on a mesh.

$$\mathcal{P}_{Functional} = \iiint_{Conductors} \left[\rho \mathbf{j}^2 + \frac{\partial(\mathbf{B}\mathbf{H})}{\partial t} \right] dv \quad (1)$$

where ρ is the electric resistivity, \mathbf{j} the current density, \mathbf{B} the induction and \mathbf{H} the magnetic field.

A first idea was to improve the mesh by minimizing this functional with regards to the node position. This find of approach was successfully tested in magnetostatics [2]. But there is the problem of the time-harmonic case, which cannot be turned into a classical variational problem [3]. The solution of this particular problem is a saddle point obtained writing the stationarity of the complex form of (1). As we were looking for a general method that can be applied to every case we move on to a posteriori error evaluation.

B. Local conservation of the power

The main idea that lead to the new criterion was that a good mesh should ensure energy quantities calculation. Therefore we propose to evaluate locally i.e. on each element a power balance.

On the one hand, we compute the power spent in the element:

$$P_{Spent} = \iiint_{\Omega_i} \left[\rho \mathbf{j}^2 + \mathbf{H} \frac{\partial \mathbf{B}}{\partial t} \right] dv \quad (2)$$

On the other hand, we introduce Poynting's vector, to compute the power supplied in the element:

$$P_{Supplied} = - \iint_{\Gamma_i} [\mathbf{E} \wedge \mathbf{H}] ds \quad (3)$$

where \mathbf{E} is the electric field.

The difference between (2) and (3) allows to evaluate the error on the local conservation of the power, on an element:

$$\mathcal{E}_{element i} = \left| P_{Spent} - P_{Supplied} \right|_{elt_i} \quad (4)$$

This criterion is generic, but it is more suitable to $\mathbf{T}\text{-}\Phi$ formulations [1]. In this case, (4) allows to check the precision on the Maxwell-Faraday equation, which drives the induced phenomena.

III. ABOUT ELEMENT ORDER

To evaluate (3), and more generally any quantity on the element edge, we can choose either to use the fields in the element, or in the neighbor elements. If we follow the idea that the mesh has to be self-consistent, the method using the field in the element appears more suitable. Moreover, it is faster because it does not need to recover the element neighbor. Unfortunately, it implies that the approximation on the element is accurate enough i.e. to use second order elements. With first order elements, it is necessary to use the neighbors to evaluate a relevant error. However, the interest of the new criterion (4) is that at the first order, it points out the good regions, thanks to its energy properties [4].

IV. APPLICATION TO A 2D HEATING INDUCTION CASE

We consider a heating induction case, where a massive conductor is excited by a coil in the time-harmonic range.

To complete the approach of adaptive meshing, we introduce here a meshor based on the bubble meshing technique [5]. This meshing technique, based on both adding and moving nodes, is detailed in [6]. The mesh is adapted using the error criterion (4) in the conducting region. After few iterations, the local error is decreased (Fig. 1) and the global power quantities convergence is ensured. With the same number of nodes we ensure a better precision both on the Joule losses and on the magnetic power (Tab. 1).

In the air region, the mesh is modified thanks to the bubble meshor, but only according to geometry consideration, in order to take account of the modifications in the conducting region. This regularization ensures high quality elements [6].

	Reference (fine mesh)	Starting mesh (64 nodes)	Refined mesh (110 nodes)	Normal mesh (110 nodes)
P_j	0.0070 J	0.017 J	0.0082 J	0.012 J
Dev.		142 %	17 %	71 %
P_{mag}	0.0064 J	0.0031 J	0.0052 J	0.0034 J
Dev.		52 %	19 %	47 %

TABLE 1: COMPARISON BETWEEN GLOBAL POWER QUANTITIES ON DIFFERENT MESHES

V. CONCLUSION

We have presented a new way to evaluate the meshing error in massive conductors, allowing to adapt the discretization to the skin effect. The criterion was coupled with a bubble meshor, in order to have a complete adaptive meshing technique for massive conductors. The results presented validate the method, but further developments will include convergence and CPU time benchmarkings.

The extension of the adaptive meshing technique will consist in defining an error criterion in the air, compatible with the energy-based criterion we proposed for the conductors. As the whole method is generic, its validity is ensured for 3D cases.

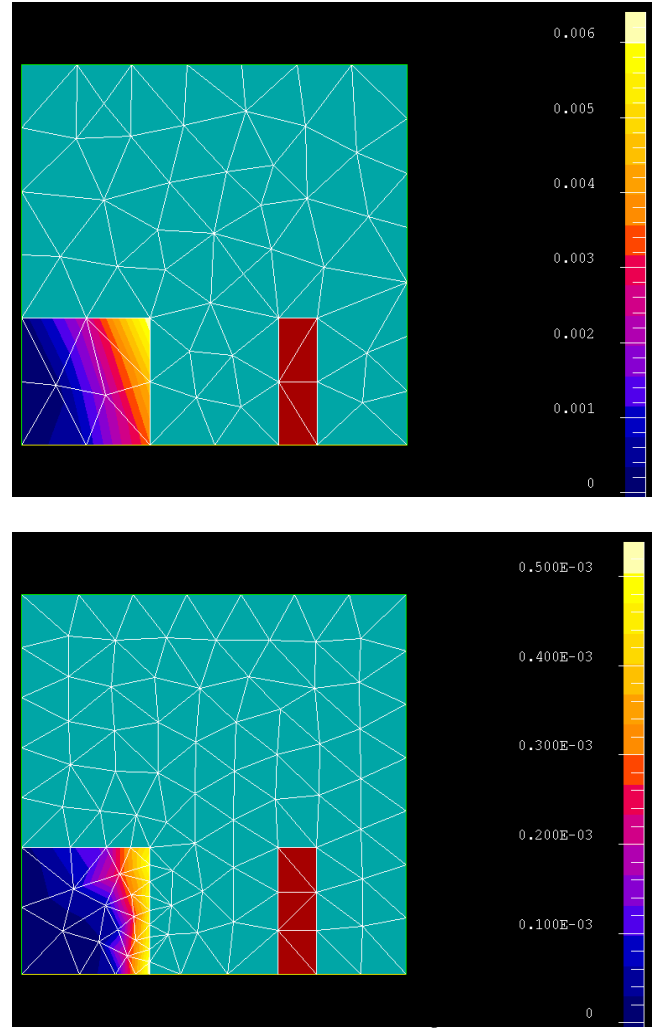


Figure 1. 2D induction case modeled with Flux[®]. Error with the criterion (4) in the conducting region for the first mesh (top) and for the refined one (bottom). The local error is divided by 10. The mesh is refined in the conducting region to match the skin effect, and a regularization is performed in the air thanks to the bubble meshor.

VI. REFERENCES

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